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OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

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Project Director: Dr. L.H. Olson

Sponsor: NASA - Ames Research Center, Moffett Field, CA

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Date 4/27/83

Project Title: Engineering ~~Desing~~ and Fabrication of a Prototype State of the Art Space Suit

Project No: E-27-603

Project Director: Dr. L. H. Olson

Sponsor: NASA-Ames Research Center

Effective Termination Date: 2/14/83

Clearance of Accounting Charges: 2/14/83

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- [x] Govt. Property Inventory & Related Certificate
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E-27-603

SEMIANNUAL REPORT ON NCC2-119

Engineering Design and Fabrication of a State-of-the-Art Space Suit

PRELIMINARY DESIGN TASK ANALYSIS

Part I. Fabric Coating, Lamination, and Molding

NOT A SPECIFICATION

presented by

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For Period Ending: 8/8/81

PRELIMINARY DESIGN TASK ANALYSIS

"AMES" AX-4 PRESSURE SUIT

NOT A SPECIFICATION

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CONTENTS

1.0 INTRODUCTION

The basic goals of the research and development efforts relating to the art of space suit design should be reveiwed. Through recent years there has been movement toward a concensus that major advances in the design of pressure suits for USA astronauts are needed. This document is a quick overview, reflecting the opinions of the writer. The purpose is to facilitate review (and) correction) by others.

a) As the space program requires more EVA, such as construction work in orbit, the need for super-reliable protective systems increases.

b) The astronauts need maximum mobility in the zero-gravity conditions.

c) Additional protection from radiation is needed for altitudes above 300 nautical miles.

d) Suit pressure should be in the order of 8.0 psi; rather than 4.0 psi.

e) The advantages of modularity, and long life, of components should be exploited- e.g. A super-reliable component, such as an elbow joint, could be used on, say, 50 different missions - by 30 different astronauts. Its status could then be changed to "Training Suit Component" for further usage. Under this rationale, investment in super-reliable, 8 psi, components is cost effective as well as advantageous to each user.

1.0 (Continued)

The following criteria are presented informally as suggestions by the writer. Understandably the actal criteria will be formulated at a "management level" after review and analysis. The presentation does represente a line of reasoning thought to be reasonable and appropriate to the goals we seek.

1.1 Suit Pressure

Operational Pressure	8.0 psi
Proof test of each component	12.0 psi
Periodic proof pressure during cyclic testing of a joint	12.0 psi
Burst Pressure Test (one time only)	20.0 psi
Proof pressure of assembled suit	12.0 psi

1.2 Cyclic Life of Flexion Joints

Except in the gloves	Two million cycles
In the gloves	200,000 cycles

1.3 Cyclic Life of Ball Bearings and the Bearing Seals — 3.0 million cycles

1.4 Torque limitations for flexion joints and rotary joints shall be comparable to the values demonstrated in the NASA-Ames AX-3 pressure suit.

1.5 Leakage through sealed bearings shall be comparable to the NASA-Ames AX-3 pressure suit. Actually, we could tolerate a doubling of the leakage rate shown in that suit.

Leakage through the joining of the modular components shall be negligible. Each joint shall be sealed by an O-ring.

1.5 (Continued)

Leakage rates at the wrist connectors, the helmet connector, and the body seal closure shall not exceed the rates allowed for the 4.0 psi "shuttle" suit.

1.6 Leakage through the fabric lamination shall not be detectable. (A component which loses air can be used in training suits).

There shall be no leakage where fabric elements are joined with the metal rings at each end of the suit component.

1.7 Wherever feasible, the fabric wall laminations shall be made of woven tubular elements.

In principle; the fabric <u>shell sections</u> shall not require restraint "lines" - <u>Convoluted</u> Sections, at the flexion joints, will be restrained from stretchout due to pressurization.

1.8 Fabric convolutions shall be formed precisely so that the flexing (or rolling of installed joints will be totally free of wrinkles which would seriously shorten the life of the joint.

1.9 Whenever feasible we shall avoid sewing of fabric elements - or attaching items such as webbing (or USA flags, etc.) by sewing.

1.10 The pressure suit for 2 specific astronauts shall be assembled from a stock of flight-certified modular components. Most of the components may have been previously used in numerous missions (re-certification, and strict storgae procedures, were required when the items were returned to "stock"). The assembled suit is proof-tested and examined for leaks and any evidence of deterioration.

1.11 Rigid shell sections of the suit may be of metallic construction, or they may be constructed as filament reinforced plastic. Both types of construction may be used.

Metal shell sections may be made from tubular stock (electron-beam welding optional) which is formed by the "Magneform" method. These shell sections will require welded-in-place metal rings at each end of the tube.

Metal shell sections can be made as investment castings (for precision and thin walls) using aluminum alloy or stainless steel.

1.12 Sizing elements shall (usually) be made as lathe-cut aluminum parts. Each end of the ring shall have a groove of half-circle cross-section which accepts the fail-safe wire form assembly. Each end shall be capable of being sealed by a conventional O-ring.

1.13 Sizing elements shall be provided for the shank, the thigh, the forearm, and the bicep areas. We should also anticipate the eventual demand for torso length sizing.

A sizing option to be noted is that the sizing may simply be omitted, for the shortest configuration of a given suit segment. Another option is the usage of two sizing rings, in tandem, at a given segment.

1.14 Tubular fabric elements shall be clamped to each end ring by a solid metal hoop which has been reduced in diameter by the "Magneform" method. Indestructive testing (or heavy usage) the fabric sleeve shall fail while the magnetically-formed joint has not failed.

This joining of fabric to metal shall be hermetic and shall satisfy NASA fail-safe criteria for structural integrity under all conditions.

1.15 The suit components, and the assembly methods, shall have all the necessary attributes to permit characterizing them as "super-reliable" and "super strong". This would be established by cyclic testing, and by pressure testing to 20.0 psig, as specified elsewhere.

2.0 FABRIC COATING PROCEDURES

2.1 The appropriate procedures, material selections, and mixing ratios will be formalized by textile engineering personnel at Georgia Institute of Technology.

2.2 The "production" coating may be done at NASA-Ames Research Center by technicians who can "stay with" the process.

2.3 Special attention shall be given to the possible safety hazards relative to the use of the solvents and chemical formulations. Processing and curing of the end-item assembly will generate hazardous vapors and fumes. See the attached "Material Safety Data Sheets".

2.4 It is the writers understanding that two cylindrical sleeves will be coated, as necessary, and placed concentrically over a cylindrical mandrel.

The (Dacron) fabric will be slightly shrunk by the application of heat, so that the two fabric layers are both tightly fitted to the mandrel; and thus to each other.

It will be necessary to preclude air entrainment in the interstice between the layers of fabric.

As the shrinkage heat is applied, organic and/or solvent vapors will be generated. It is very probable that the concentrations will exceed the safe Treshold Limit Value. The TLV"s for the chemicals being used have not been established. This often means they are "controversial" and, by inference, hazardous.

It is suggested that all recommended safety equipment be used and that high capacity ventilation systems be used.

2.5 When the cylindrical lamination has been "cured" (outgassing stops) at the shrinkage temperature used at this stage, the lamination may be removed from the cylindrical mandrel.

The laminate should be supported in its cylindrical shape and several in a plastic container which can be charged with a non-reactive gas.

2.6 A subject of concern to this writer is the ambiguity, or confusion, caused by the fact that some which have been used to "name" the steps of the coating procedure may be used interchangeably (correctly) under some circumstances, but have different meanings when certain conditions are changed.

2.7 This commentary proposes that the various steps, or stages, in the coating process be given specific names, and that these names be used only when discussing that step.

A "set" of names for the steps is proposed - subject to change, of course.

Step	Name	Prepresentation of the process
I	Cleaning	a) Decrease the fabric with 100% MER by agitating in solvent 2-3 minutes. b) Air dry at ambient temp. in a clean bench which removes vapors.
II	Primary Coat	a) Modify the viscosity of Impranil 398 to ____ Cps using a diluent composed of (1/1) PMF and toluene. b) After dilution, add Mondur CB-75 in the ratio of ________. c) De-gas ______ minutes in vacuum. d) Apply coating to one side of the fabric using a doctor blade. Set blade at gap of ____ inch. e) Cure this coating for ___ hours at ____ temperature before applying & subsequent coating.
III	Secondary Coating	a) Modify the viscosity of Impranil 392 to ___cps using a diluent composed of 15 parts DMF, 30 parts Toluene, and 20 parts isopropyl alcohol.

2.7 (Continued)

Step #	Name	Representation of the process
III	Secondary Coating	b) De-gas ____ minutes in vacuum. c) Apply coating to priming coat using a doctor blade. Set the blade at a gap of ______ inch. d) Cure this coating for _____ hours at _____ temp. before applying a subsequent coating.
IV	Tertiary Coating	a) Prepare Impranil 392 as specified in para. (a) and (b) in step III. b) Apply coating to secondary (previous) coat using a doctor blade. Set the blade at a gap of ____ inch. c) Cure this coating for ____ hours at _____ temp. before applying a subsequent coating.

Note: Additional build-up may be done by repeating step IV.

3.0 LAMINATED FABRIC CONSTRUCTION

3.1 We are concerned here with single wall tubular fabric laminations. Usually there will be two fabric sleeves assembled concentrically with urethane coatings applied to the interface surfaces. Sec section 2.0 for coating procedures and partial curing of the urethane.

3.2 The fabric lamination is first assembled as a cylindrical sleeve. this assembly is subsequently placed over a forming tool and shrunk to fit that shape by applying heat. (The Dacron fabric will shrink approximately 18% when exposed to 392^{O}F thermal environment for ____ minutes).

3.3 One fabric layer will be a cylindrical sleeve of plain (square)

3.3 (Continued)

weave. The "threads" shall be high tenacity Dacron fiber which provides the required tensile strength.

The other fabric layer will be a cylindrical sleeve which may be either weave or knit construction. This layer is light weight. Its functions are:

a) Provide a low friction interior surface

b) Protect the urethane hermetic film

c) Facilitate over the corners of the forming rings, as the fabric laminate is shrinking.

3.4 The denier and thread count of each structural sleeve shall be consistent with strength requirements of the lamination in which it is used. It is also understood that even though the smaller diameter sleeves could be relatively lightweight, we are also concerned with abraision life and puncture resistance. The toroidal convolute design permits the usage of a substantial lamination thickness (e.g. .030 inch) in the smaller joints.

3.5 Strength Criteria

a) Elongation at 8.0 psig shall not exceed ½%.

b) Elongation at 16.0 psig shall not exceed 1¼%.

c) Elastic recovery shall be 99.8 % after pressurization to 16.0 psig.

3.6 It will be understood that a larger shell, or convolute, such as would be used in the torso section, may be built-up using two "heavy" layers of fabric.

3.7 We do not rule out the possibility of using one "thick" layer between the two "thin" layers. Abrasion which partially wears thru a thin layer would expose a contrasting color of elastomer sealant. A warning of possible weakening.

3.8 Other sections of this "analysis" deal with coating and the Heat-Shrink scenario in greater deatil.

4.0 <u>FABRIC HEAT-SHRINK SCENARIO</u>
(for a toroidal convolute)

4.1 The technician is provided the equipment described under sections 5.0 and laminated sleeving described in sections 2.0 and 3.0. A "set" of forming rings as described in section 6.0 is provided.

4.2 Set-Up of Forming Rings

a) A succession (or a "set") of forming rings are prepared for placement on a horizontal spindle. Each forming ring is an assemblage of parts which can be separated while the ring is constrained axially between the deep grooves of "unstretchable" fabric laminate.

b) The forming rings are spaced (with pre-determined gaps) along the spindle and are restrained temporarily at their discrete spacings.

4.3 The pre-assembled straight cylinder laminate is placed over the forming rings. A clamping band is placed on the laminate at each end.

4.4 a) Move the oven into its closed position and latch.

b) Turn on the chart recorder for oven temp.

c) Start the spindle rotation drive.

d) Set the oven temperature controller at ___^{o}F and turn on the oven. (The set print temperature should shrink the sleeve about 2%, or enough that the sleeve "grips" the support rings).

e) Hold the set print temp. for _____ minutes.

4.5 a) Release the mechanical restraint of the support rings. (Close the oven, if necessary)

b) Raise the oven temp. to ____^{o}F and hold for about ____ minutes. This effects a shrinkage of about 5 to 7 precent.

c) Turn off oven heat; open oven; stop spindle rotation.

d) Quickly place Viton O-rings (.103 c/s) at the midpoint between each forming ring.

e) Reclose and latch the oven. Start spindle.

f) Turn on the oven and adjust the set point temperature to about 300^{o}F.

g) With the spindle rotating, monitor the fabric shrinkage. We should induce the following simultaneous actions.

1) Forming rings move toward each other.

2) Fabric shrinks to form the "deep groves".

4.6 When the shrinkage for this temperature has apparently stopped:

a) Force the forming rims into wall-to-wall contact and secure that condition.

4.6 (Continued)

b) Raise the set-point temperature to 200°Celsius (392°F).

c) Monitor the shrinkage to determine if the fabric goes to the bottoms of the deep grooves and into the fillets of the raised heads.

d) If necessary "urge" the fabric into its fully-formed convolution.

<u>Option 1</u> Open the oven briefly and force the fabric to "move" by use of special tools.

<u>Option 2</u> Use a special tool mounted to a probe which passes through a ball joint in the side of the oven to force the fabric movement.

<u>Option 3</u> Open the oven and exchange the Viton-O-rings. Install smaller diameter (.103 c/s) O-rings; or higher durometer O-rings.

e) Maintain the oven temp. at 392°F for _____ minutes after the full forming of the convolute is assured.

<u>Note</u>: "Max-Set" oven temperature protection is set at 398°F.

4.7 The laminated fabric sleeve has now been "cured" at its final heat-shrunk form.

a) Turn off the oven heat

b) Continue forced convection through the oven for 30 to 60 minutes, to cool the fabric laminate and the forming rings.

c) Stop the spindle rotation

d) Open the oven

e) Turn off the temperature recorder

f) Remove the assemblage of forming rings and fabric (which is now bound together by the deep convolutes) and take it to a "clean bench" workstation.

4.8 Remove fastners; disassemble and remove each forming ring in succession.

a) Clean-up and store the parts kits for each forming ring in sets.

b) Inspect the laminated convolute for nonuniformity of thickness, air inclusions, possible damage to fabric, etc.

c) Trim excess length (which has been clamped during the procedure).

4.9 POST SCRIPT

It should be noted that the fabric convolute is now fully cured but no metal hoops have been incorporated at this stage.

Wire compression hoops will later be placed into the samll groves which are centered in the "crown" of each convolute.

The component end rings, which permit interchangeable assembly by the wireform method, shall be different from each other - giving the component polarity. One end is "proximal" which means it is more near the torso.

The fabric sleeve shall be bonded and mechanically retained to the end ring. A solid hoop (6061-0 aluminum) is first placed over the fabric sleeve and then reduced in diameter by the "Magneform" method of high-velocity forming. The aluminum ring may receive about 25,000 psi compressive forces in this process.

It should be supposed that the end rings will also be reduced in diameter also unless they are supported by a disc-like plug during "Magneforming".

E-27-603

SEMIANNUAL REPORT ON NCC 2-119

Engineering design and Fabrication of a State-of -the-Art Space Suit

PRELIMINARY DESIGN TASK ANALYSIS

Part II. Hard Components

NOT A SPECIFICATION

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For Period Ending: 3/1/82

PRELIMINARY DESIGN TASK ANALYSIS

"AMES" AX-4 PRESSURE SUIT

NOT A SPECIFICATION

Prepared by

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4.9 (Continued)

It seems preferable to add these rings and compression hoops to the convolute rather than to place the end rings into the heat-shrink process and thus give up some desion freedom.

5.0 WORK STATION ARCHITECTURE

(For heat-shrinking tubular woven fabric)

5.1 Environmental Considerations

a) There should be a dedicated "clean room" space adequate for the heat shrinkage work station, a "clean bench", and storage facilities.

b) The "clean room", the "clean bench", and the "oven" shall have air replacement (ventilation) which safely removes fumes and vapors which are toxic or combustible.

c) The environmental (air conditioning) system shall control temperature and humidity, and shall remove particulates greater than _____ microns from incoming air.

d) There shall be a means to direct ample flow of fresh air onto the heated fabric workplace when the "oven" has been moved away.

e) Emergency exits and safety equipment, to protect workers from fire and chemical hazards, shall be provided. (See Safety Data Sheets from Mobay Chemical).

5.2 Electrical and Thermal Protection.

a) The oven shall meet NEMA and/or UL requirements for electrical and thermal hazard.

5.2 (Continued)

b) Ancillary electrical systems; such as a rotational drive for the workplace support spindle, illumination, thermal sensors and controls, recording instruments, etc. shall meet applicable industrial safety codes.

c) The construction of the oven, the spindle system, workbench, etc., shall preclude (as praticable) accidental burns, cuts, mashing of fingers, etd.

5.3 The Workbench

a) It is presumed that the heat-shrinkage workstation should be mounted on a stock workbench approximately 36" wide by 96" long by 30" high.

b) The workbench shall be a rugged construction which is resistant to warpage or sagging under load. The table top should have suppicient thickness to permit secure bolting of pre-built "table-top" mechanisms.

c) It is proposed that McMaster Carr table Cat. No. 4754'Y81 be purchased. The table is nominally 36" x 96" x 30" high. It has a drawer, a shelf, a stringer, 6 legs, and raised backplate and endplates. The "above-surface" portions of the backplate and endplate should be removed.

The 12 size (.105 inch) table top can be "doubled" with plate stock if additional stability is desired.

5.3 (Continued)

d) There should be unobstructed floor space at least 42 inches wide all-around the workbench. The opened drawer is permitted to occupy the 42 inch clearance. The drawer may be moved to add structure.

5.4 Cantilevered Spindle

a) It is understood that the technicians will be sliding a straight cylindrical fabric tubing over an assemblage of forming rings just prior to the heat-shrinkage procedure. The horizontal cantilevered spindle scheme provides convenience for placing of the fabrics accessibility for "working" the fabric, and quick opening and closing of the oven.

b) The spindle shall be coupled to an electric gearmotor which may rotate the spindle approx. 2.0 RPM. There shall be on-off switchline, and a signal lamp for this system.

c) There shall be a mechanical clutch which permits manual rotation of the spindle even though the high ratio (self-locking) gearmotor is mechanically engaged by a chain drive, or equivalent.

d) The drive system shall be protectively shrouded to prevent accidental injury, or interference with normal operations.

e) The spindle support structure shall be adjustable at installation. When "perfect" alignment is obtained, match-drilling and pinning of alignment holes can be done.

5.4 (Continued)

f) The spindle center line shall be horizontal. The center-line height shall be approximately 25 5/8 inches above the top surface of the workbench. The exact dimension is dependent upon the "oven" construction and its means of translatory movement.

g) The spindle shall be made of steel tubing, as shown in No. 4-22-1981-1, Revision A. The through hole permits placement of a bar which has c surfaces to atuate the pins which can lock the axial position of the forming rings.

h) The spindle is supported in two self-aligning bearings and is restrained against axial movement. (Use a 2½' clamping collar).

The bearing in the "sixth wall" of the oven must tolerate 400^{O}F temperature. Use SKF #GE60CS-2Z which is good for 525^{O}F and dosen't require lubricant.

i) We should have a "blank" shaft which serves as a space, and is available for modification to permit an alternative "production" scheme.

5.5 The Ovens

a) it is now persumed that we should use a high quality, commercially available oven. The electrical system for heating, forced convection, controls and displays are built-in and ready to use.

5.5 (Continued)

b) Temperature recording may be done by a "Honeywell Electronik" 10 inch disc chart recorder which is thermocouple actuated. This unit receives its input through electrical wiring, in circuit with the control system. The recorder may be fixed to the bench or to the oven itself.

c) Electrical service to the ovens is 240 volt, 60 H3 A.C., 1 pahse, 4.6 KVA. The oven wiring is complete and totally enclosed. "Internal" wiring is complete and totally enclosed. "Internal" wiring meets the amended N.E. code and NEMA standards. There is a terminal box for service connection. Note that service wire must be somewhat flexible because the oven is frequently moved.

d) The inside dimensions of the basic oven are 20" wide, 18" deep, 20" high. This will accomodate the tooling, etc. for a laminated fabric waist joint convolution.

e) Because the oven conventionally has its control console directly beneath the door, we need a way to reverse that situration. The remedy is as follows:

1. The manufacturer adds a second door opposite to the existing door.

   This door will be detached, modified, and installed to the spindle support structure as the "sixth wall".

2. The original door will be modified to include a window 9¼' wide by 12 3/4 high.

3. The controls (and the original door) are faced away from the spindle support section.

5.5 (Continued)

f) The oven weighs approx. 325 pounds. It can be supported, and easily moved, by using four "Autotrack" ball transfers , Part No. 1361 (General Bearing Corp.)

   Each ball transfer has 350 lbs capacity and may be installed "ball down".

   Two groved tracks 32 inches on-center are required. Track length is 34¼ inches. See Dwg. No. 4-22-1981-1, Revision A

g) The oven shall have complaint gasketing which seals the "open" End when it is drawn tightly against the door being used as the "sixth wall".

h) There shall be an adjustable latch at each side of the oven; to draw the oven against the fixedly mounted door being used as the "sixth wall".

i) The "sixth wall" shall be bored 3.750 dia. at the center to receive a welded-in-place sleeve which houses a maintenance-free spherical bearing. See SKF# GE60CS-2Z (60mm Bore)

j) The oven shall have internal lighting. Preferably, there would be long, slender, lamps parallel to the spindle axis placed in the longitudinal interior corners.

k) The oven shall incorporate heat-tolerant mirrors which permit viewing of the convolutes by looking through the window in the accessible door at the end.

5.5 (Continued)

l) A potential addition to the oven is small "windows" along the sides for direct viewing of the convolute forming action. We can use a circular double pane construction, which gives 4½' viewing aperture, installed with screws.

m) Another potential addition to the oven is through-the-wall probes by which the fabric convolutes can be "urged" into conformal position in the deep groves which exist when the forming rings are adjacent.

The probes would move axially, rotate, and tilt. The probes can pass through 17mm bore spherical plain bearings. (SKF # GEH 17C) which tilt $\pm$ 19^{0} of arc.

Bearing mount would be pre-built for installation in special holes added below the circular view ports.

n) Space for comment

5.5 (Continued)

o) Suggested Oven Purchase

Source: Blue M Electric Co.
Blue Island, Illinois 60406
Phone (312) 385-9000 (Larry Serafin)

	List Price
Model N: POM7-206C (complete)	1395.00
Additional "stock" door in side opposite original door.	300.00
Glass window (9¼ wide x 12 3/4 high) added to the original door	115.00
"Honeywell Electronik" circular chart recorder, 10" dia., 24 hour. Installed (location to be decided)	640.00
F.O.B. Blue Island, Illinois	$2450.00

- We should acquire spare thermocuples
- Also spare charts and pen cartridges for the recorder should be obtained.
- We should ask "Blue M" about a filter for the oven air intake.
- We should ask "Blue M" to move the electrical box (power) to the side of the oven.

See "Blue M" cata;pg Mp/ 56-181, pp. 46,47,48 & 49 for specific data on this oven.

See pp. 12 thru 16 for controls system & warranties.

6.0 FORMING RINGS FOR TOROIDAL CONVOLUTE

6.1 A "set" of forming rings is required for each size, or length, of toroidal convolute.

6.2 The initial technology development shall be focused on the elbow toroidal convolute. There will be short convolutes "above" and "below" the rigid elbow shell - as in the AX-3 suit.

Our dimensions can be similar to those for the AX-3 elbow, in which the mandrel O.D. was 5,350 and the vee groove root diameter was 4,780.

We may assume a lamination wall thickness of .030 inch for the elbow and knee convolutes for tool design purposes.

6.3 The challenging problem areas related to the forming ring design.

a) Because the fabric sleeves are shrunk onto the form rings (18% shrinkage) removal of the tooling becomes a problem. Note: We cannot consider "peeling" the laminate off the form tooling.

b) Because the fabric shrinkage is basically equal in the warp and fill directions, it is necessary to space the forming rings so that they will slide toward each other as the fabric shrinks. The optimum design, and procedure, would cause the forming rings to be "solidly" adjacent at an oven temperature of about 350°F and then cause the diametrs shrinkage to form the fabric into the bottom of the grooves at 392°F. We can use "Viton" O-rings of .103 cross-section to urge the flow of fabric into the grooves. This subject is discussed in more detail in Section 4.0 (Fabric Heat-Treat Scenario).

6.3 (Continued)

c) Because the rings are quite narrow (as compared to their outside diameter) it is prudent, probably necessary, to stabalize each ring against tipping - so that a ring cannot be "locked" against sliding.

I would propose investigating the use of "Thomson" ball bushings placed in each of four sectors of a forming ring, so that the ring assembly can be guided by ¼" diameter rods which are secured at one forming ring and pass through all of the forming rings.

Two solid rings which support the alignment rods can be fixed to the spindle. The "breakdown" rings, to which the fabric is formed, could "float" along the alignment rods by means of their "frictionless" ball bushings.

7.0 FLEXION JOINTS

7.1 In the present effort we will be making flexion joints for the elbows, the knees, the thighs (abduction/adduction) and the waist. We may assume, for now, that a vendor will develop the compound flexionjoints for the wrist and the flexionjoints which comprise parts of the glove.

7.2 We should give priority to the development of the toroidal convolute configuration, as opposed to rolling convolutes.

a) A toroidal convolute has been cycled, at pressure, through 3.3 million complete cycles without failure, and without significant wear.

b) There is no confirmation that a rolling convolute joint will survive more than, say, 200,000 cycles in a space suit application.

c) It is reasonable to suppose that attainment of one million cycles, in a rolling convolute, could be a technical challenge.

7.3 It must be kept in mind that the toroidal convolute has its peculiarities which make it somewhat difficult to produce.

7.4 Problem areas to be addressed in the present effort include:

a) Forming the relative deeg grooves of the convolute.

b) Attaching a restraint line alignment device to each convolute.

c) Obtaining a hermetic lamination of two woven sleeves, without entraining air between the two layers.

d) Obtaining a heat-cure which stabilizes the fabric shape and dimensions and matures the chemical reactions of the urethane coatings which bond the layers and provide hermeticity.

e) Providing laminate tensile strength such that elongation, in the warp and fill directions, do not exceed ½ per cent at 8.0 psig, 1.25 percent at 16 psig, and will not fail at 20 psig.

f) Elimanating residual stress, in the cured shape, so that

7.4 (Continued)

puckering or wrinkling will not occur in the free form laminate after

7.5 The materials, procedures, processes and suggested facilities criteria are discussed elsewhere in this report. The compression hoops and "restraint lines" are also discussed elsewhere.

7.6 It is properly noted that we should not arbitrarily rule out rolling convolute joints at this time.

It is known that "Bellowfram" convolutes (which are thin and well-protected) can be cycled many times in production machinery applications.

There is a reasonable liklihood that research approaches along new lines of investigation would yield a large increase in cycle life.

8.0 FABRIC SHELL SECTIONS

8.1 Although we are giving priority to the challenges in heat-forming cylindrical sleevings to the engineered shapes for flexion joints, we should keep in mind the necessity for laminated fabric shell sections.

8.2 It could be argued that rigid (e.g. metal) shell sections are more appropriate - being especially useful at the altitude of geosynchronoms orbit. Investment cast transitions would be cost-effective because the meatl end ring function is incorporated and there are no fabric-to-metal joints.

8.3 There should be a determination as to which fabric shells (if any) can be made from cylindrical, woven, tubing. It should also be determined whether hest shrinkage techniques are to be used and, if so, how much shrinkage is to be effected.

8.4 There may be shell sections which are conical in shape. The question arises as to the practicality of weaving a conical tubing. Another question arises as to the practicality of heat-shrinking a cylindrical sleeve onto a conical mandrel.

8.5 We will be required to address the question as to whether we are concerned, in this effort, with a need to make hand lay-ups of certain shell sections. If so, we need to decide if prior art is to be used. Perhaps a new "production" technique should be researched.

8.6 Some pertinent questions:

a) Do we make a fabric laminate shell section for the upper arm transition?

b) Do we make a fabric laminate shell section for the forearm transition?

c) Do we make a fabric laminate shell section for the thigh-transition?

d) Do we make a fabric laminate shell section above-knee transition?

e) Do we make a fabric laminate shell section for the below-knee transition?

f) Do we make laminated fabric boots?

g) Do we make fabric laminate shell sections for upper and lower torso transitions?

- The Shuttle hard torso shell (HTS) was first produced as a weldment of metal stampings and machined parts. When changes were necessary, the Hamilton-Standard people went to Fiberglas Reinforced Plastic fabrication in order to meet delivery schedules. In both cases the HTS has been extravantly expensive. Also, the "FRP" construction has shown signs of unreliability.

  I would suggest that the Hard Torso Shell would have greater integrity, reliability, and service life it it were produced as a casting. Cost savings if, say, 20 pieces of 5 different sizes (100 pieces) would be in the order of 5 to 8 million dollars.

  A principal advantage of castings is the quality control, certification, and respectability which is provided by adherence to aerospace standards, by approved vendors. Aluminum alloy 356-76, or 356-751, would be appropriate.

- Metal shell sections can be produced by shaping the tubular portion by high-velocity forming (e.g. "Magneform") and then attaching the tube to end rings by magenform "swaging" or by welding; whichever is appropriate.

- The smaller shell sections, other than sizing rings, would be economically produced as precision castings.

9.3 This section explains why the previous design constraints are "outdated". Letters match.

a) The "Shuttle" vehicle has enormous payload capability - super-strength and super-reliability of the suit components (and their assemblage) justifies a moderate increase in weight. It is reasonable to increase the weight of each suit by 15 pounds, if necessary, to gain the enormous advantages which can be obtained by abandoning the "tailor shop" approaches used heretofore.

b) The "Shuttle" suits are stored in the "Shuttle" vehicle airlock. The Upper Torso Section, with life support system installed, is wall-mounted. The Lower Torso Assembly, which is preassembled, is fairly bulky. We should easily be able to store the "hard" Lower Torso Assemblies in the air lick.

c) We now have an excellent scheme, for modularity, by which anyone within a certain range of heights can be fitted with a super-reliable pressure suit in less than two thous.

d) A very successful 8.0 psi suit exists. A partial "suit installed in the wall of the Lunar Sample Receiving Lab (vacuum) chamber was used at 14.7 psi ... We can design an 8.0 psi "flight suit with confidence... The advantages of mixed-gas, 8.0 psi pressurization, have been denied too long.

e) The bladder and restraint garment methodology is simply archaic. It derives from a sewing machine approach to garment construction as opposed to pressure vessel engineering.

9.4 We now have a good argument for using metal shell sections as much as possible.

- In the modular system, a specific suit will be assembled from numerous components. In most cases the assembly method used will use the wireform system described elsewhere in this paper. Usually, each end of a module will require a substantial metal ring which provides its part of O-ring sealing and wire method assembly. It would be most convenient if these metal ends are integrally part of a one-piece metal shell, or ring.

- Metal shells are very strong; so it should be rather easy to satisfy the 20 psi burst pressure test. We could call this "super-strength", in comparison to "conventional wisdom" suits.

- Metal shells will resist micrometeoroid penetration and the added radiation of altitudes above, say 200 nautical miles. The suit can be used at any orbital altitude.

- The metal shells can be considered "super-reliabel" as compared to soft goods technology.

- Metal shell sections are cost-effective because they can be produced using established methods and should last :forever". As off-the-shelf components used in a modular scheme, each shell section can be used many times. Parenthetically; problems of fungus, bacteria growth, organic decay, or chemical deteoriation are generally eliminated.

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